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Results of A3 absorption measurements performed in southern Spain between 1968 and 1976 are communicated. Some details of the experimental set up are described. The discussion is mainly confined to the shape of the diurnal variations. It turns out that this parameter has a distinct physical meaning which change with season. The result suggests that this is caused by meteorological effects in the neutral atmosphere. Some examples which point into this direction are communicated.

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FINAL REPORT

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PART I:

RESULTS OF GROUND-BASED RADIO WAVE ABSORPTION MEASUREMENTS PERFORMED BETWEEN 1968 AND 1976 IN SOUTH WEST EUROPE (SPAIN): PHENOMENOLOGY

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CONTENT

A

1. INTRODUCTION

This report summarizes results of radio wave absorption measurements. These measurements were executed in Spain at 41° N between 1967 and 1976 to support rocket-borne in-situ measurements of certain parameters of the D-region atmosphere. The relatively long period during which these measurements were performed continuously and a high accuracy of measurement allowed to eludicate some details of the temporal variations of the state of the D-region atmosphere but also the limitations imposed to the interpretation of this kind of measurement.

The report is confined to results of ground-based experiments only. By necessity this review must remain incomplete. Aspects of detailed ion chemistry, for example, are not discussed. The reader is referred to other sources, e.g. Arnold and Krankowsky [1] [2] and to a recent review published by Offermann [3].

2. WINTER ANOMALY

Radiation incident to the earth's atmosphere produces ionization if its energy is sufficient. The primary constituents are positive ions and free electrons. The electrons tend to produce negative ions at heights below about 65 - 75 km but most of them remain free in height levels above about 75 km during daytime. Free electrons present in the height region between 60 and 90 km (in the D-region of the atmosphere) can be observed conveniently and with little experimental effort from the ground as an attenuation of radio waves reflected in the E- and F-region of the ionosphere. Different experimental set-ups for for such wave propagation measurements are feasible. Their merits and deficiencies are quite extensively discussed in "Manual Ionospheric Absorption Measurements" [4].

All ground-based wave propagation experiments have in common that the <u>integral</u> electron content of the D-region, weighted with the electron collision frequency is measured. An ionization which consists of only positive and negative ions (the latter being produced by a rapid attachment of free electrons to neutrals) cannot be detected by those wave propagation experiments though such processes might be of great importance for the understanding of certain phenomena observable with wave propagation experiments.

The electron density and, by this, the amount of absorption in the D-region varies with the intensity of ionizing solar radiation incident to the Earth's atmosphere and with the variation of the solar zenith angle. As a result, the absorption varies with time of day and with season. Because of this, one should expect that the lowest absorption would be measured during the winter season, being highest during mid-summer. But all measurements of absorption performed at medium latitudes (45°) have shown (with one exception) that this not the case. Absorption measured during the winter season is at least as high as during summer, and periods of very high absorption lasting for a few days (which have a certain tendency to reoccur) are typical for winter conditions at moderate latitudes.

This deviation from what is expected is called "the winter-anomaly of radio wave absorption". Lack of knowledge about the physical processes which eventually lead to the development of an increased electron density somewhere in the D-region and experimental difficulties inherent to the methods of measurement have however caused some controversy "about the term "winter anomaly", rendering its meaning somewhat ambigous and vague. Some authors accept only the very high absorption which occurs "irregular" as being "winter-anomalous", other distinguish between a "regular" part of winter-anomaly which follows the solar zenith angle and an "irregular" part which is superposed to the "regular" winter-anomaly [5] , and another group applies the term "regular" and "irregular" to the shape of the diurnal variation of absorption.
Confusion may sometimes become complete. If one looks for the reason why so many definitions of winter anomaly are used, one finds that, at least at the beginning, almost all absorption measurements were performed in comparatively high latitudes between about 48°N and 60°N, and that the amount of radio wave absorption measured by ground-based means comprises not only absorption caused in the D-region of the ionosphere (60 - 90 km) but also contributions from heights near the reflecting point of the wave were the group velocity of the probing wave becomes low. The contribution of this so-called "deviative absorption" (which is dependent of operational frequency of the circuit and of critical frequency of the reflecting ionospheric layer) can by no means neglected, and can even form the largest portion of total absorption when the measuring circuit is not well designed. Chief of design of an absorption measurement circuit is to keep the influence of the deviative portion of the measured absorption as low as possible and as a constant fraction of the total absorption measured on the circuit. This is best met when the

reflection of the probing wave takes place in the E-region. Further, when the absorption is measured by observing the field strength of a transmitter which emits a continuous wave and is located at a distance where the ground wave is no more received, fairly accurate and reliable measurements of absorption can be made with little experimental effort.

This method of measurement is known as the A3 method and was used by us in Spain from 1967 until 1976.

In the following paragraphs, the experimental set-up and some of the results of ground-based A3 measurements gathered in southern Spain are described.

2.1. Contamination, latitudinal-dependence and spatial validity of measurements

Because most measurements of absorption were performed (up to about 1960/65) at latitudes between about 49° and 60° (mostly northern) latitude, some controversy was going on for some time if measurements at such latitudes might not been strongly influenced or contaminated by contributions from the auroral zone. In 1964 we could show [6] [7] that the winter-anomaly effect is present also at much lower latitudes (41°) and that a southern boundary of this effect exists. This southern boundary is however not constant but varies with time during the winter season. This result was later confirmed by measurements aboard ship [8] which were repeated later. [9] . It was further found that winter-anomaly absorption occurred at lower latitudes in groups of days which were well separated by shorter or longer periods in which absorption was very low. This result suggested that lower latitudes might be better suited to run ground-based and in-situ measurements designed to uncover the effects which eventually lead to winter-anomalous absorption because one has there in one winter more than one chance to observe both states of the D-region, "winter-anomalous" and "normal". Further, one has reason to believe that the results obtained in lower latitudes are probably less contaminated by influences from the aurora zone than it might be the case at higher latitudes. Both alleviates proper planning of in-situ experiments and interpretation of results.

Controversial was further the question if results of absorption measurements just mirror local conditions or if they are representative for a larger area. An early attempt to resolve this question by correlating the results obtained in Freiburg (48°N) and Lindau (53°N) yielded no significant correlation. This lack of correlation was then interpreted as a proof that absorption measurements represent mainly local variations of the D-region, but this need not be true because a low accuracy of measurement can lead to the same result. One of the first tasks which had to be solved with the ground-based measurement before proceeding further was to establish that ground-based measurements of absorption either represent just local conditions or that they are valid for a larger area.

3. The ground-based absorption measurement circuit

At network of circuits to measure radio wave absorption was installed in Spain to monitor absorption. Its first use was to decide which interpretation mentioned before was valid. The geographic location of this network is shown in Fig. 1. The A3 method was used because the technical effort remains quite low: A transmitter of medium power output (400 - 800 W) is sufficient for the measurements. Radio wave spectrum demand is at minimum because an unmodulated carrier is emitted only. Variations of the height of the reflecting ionospheric layer has only a small influence upon the result when the reflection of the probing wave takes place at the E-layer (this obviates the need to apply corrections) and receivers are available on the market which keep their calibration for a very long time. With carefully selected equipment, a measurement accuracy of about 0.1 - 0.2 dB is feasible. A further increase of measurement accuracy may be possible but renders useless because changes of antenna feedpoint impedance, changes of electric properties of the soil etc. cause apparent changes of absorption which are of same order of magnitude than the measurement error of the equipment and are hard to control.

Path length and transmitter frequency was selected to fulfil the conditions of unambiguous measurement; that is, the probing wave was reflected in the E-region during most part of the day, and the relation between deviative and non-deviative absorption remained almost constant over the whole year. To assure that only the ordinary component of the 1 x E-mode was received, the antenna at the receiving end was a $5\lambda/_2$ longwire antenna with counterweight $\lambda/4$ high, pointing to the transmitter site. This antenna favoured the 1 x E mode and suppressed efficiently the 1 x F and higher modes of propagation via the E- and F-layer. Experience has shown us later that the demand upon antenna height was less critical than anticipated: After the antenna system was destructed by a gale, financial restrictions allowed to re-install the antenna system at a height of only about 12 m. No significant difference was observed between what was obtained before

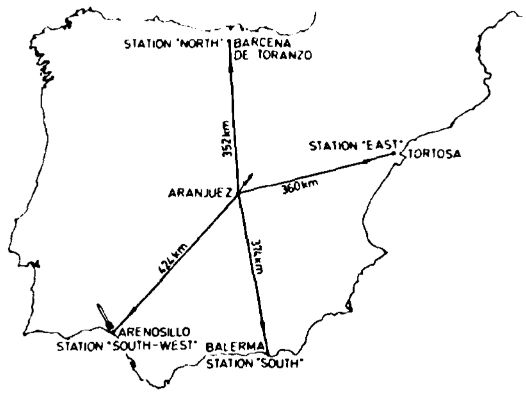

Fig. 1:

Network of A_3 absorption measurement circuit operated in Spain between 1967 and 1976. Operational frequency: 2830 KHz, transmitter power: 800 W. The circuit Aranjuez-Alceda was operated only from October 1967 until December 1968. The equipment was transferred later from Alceda to El Arenosillo to monitor absorption during in-situ experiments flown on sounding rockets.

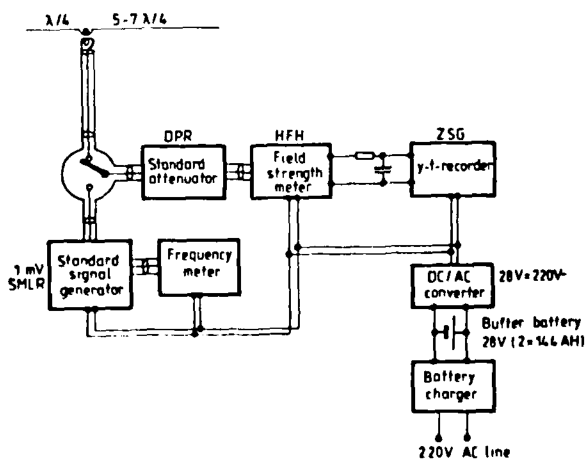

Fig. 2:

Block diagram for receiving site. Capital letters (e.g. DPR, HFH): Type designation of Rohde and Schwarz equipment used for the measurements.

and after the change. It is assumed that the rather dry soil on which the antennas were erected was the cause for this effect.

The antenna feedpoint was linked to a coaxial feedline through a ferrite matching transformer. The feedline was connected to a standard attenuator which was placed at the front end of the receiver. The standard attenuator allowed calibration of the receiver in steps of 1 dB. Because the actual value of the input impedance of the receiver depended slightly upon frequency and was different for different receivers, an attenuation of 10 dB was always left at the front end of the receiver so that the antenna would always "see" a constant impedance (in our case, 60 ohm).

The AGC voltage of the receiver was recorded on an y - t recorder on paper. The recording speed was 60 mm/h. The fading of the incoming signal would however cause a rapid variation of the AGC-voltage and would produce a smeared-out, band-like record on the recording paper which renders accurate read-outs of averages difficult if not impossible. To overcome this problem, the output signal of the receiver was integrated by a time constant of 30 sec. This resulted in a clearly-readable record. For evaluation, the peak value of receiver input voltage of each five minute interval was taken under consideration.

Calibration of the receiver was performed with a signal generator which delivered 1 millivolt output on 60 ohm. The antenna was disconnected during calibration. The smoothing time constant was taken out and the standard attenuator was connected to the source. Calibration was then done in steps of 1 dB using the standard attenuator. Fig. 2 shows the arrangement.

In order to obtain a survey about ionospheric conditions, an ionosonde was operated at the receiving site. The antenna system for this equipment was a set of three vertical rhombic antennas which was orientated perpendicular to the longitudinal axis of the receiving antenna.

Unsurmountable logistic problems prevented the installation of the ionosonde equipment under the reflection point of the probing wave used for the absorption measurment, but it turned out that the survey obtained at the receiving site was in most cases sufficient, except when strong sporadic E was present. This however, could be easily recognized as a change of type of fading of the receiving signal. The antenna setup at the transmitter and the

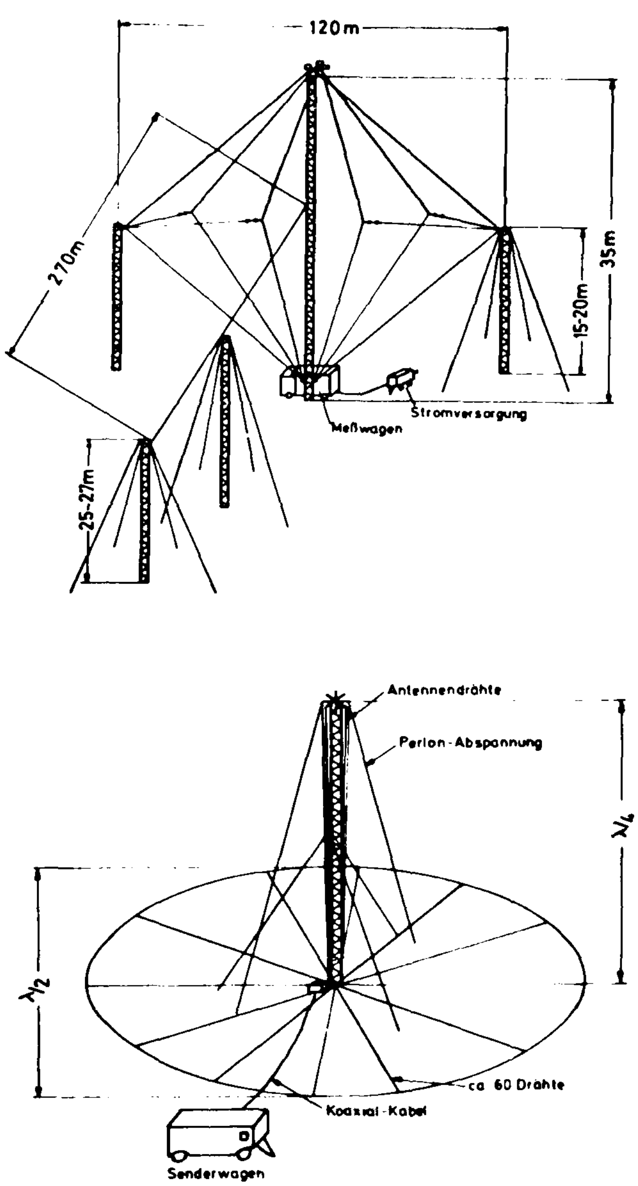

Fig. 3:

Antenna system for receiver and transmitter site receiver site is shown in Fig. 3.

3.1. Absolute calibration

The arrangement described in the foregoing allows to measure absorption on a relative scale with a fairly high accuracy. Because the results of these measurements were to be used to interprete rocket-borne in-situ measurements of electron density, absolute values of absorption had to be provided by the circuit. Absolute absorption data are obtained when the propagation loss at absence of absorption A_R, is known. A_R is the reference receiver input voltage (in dB over some reference level). The absolute amount of absorption is then given as $L(t) = A_R - A(t)$ where A is the receiver input voltage (in dB over the same reference level as A_R) measured at time t.

By principle, it is possible to calculate $_{AR}$ from the technical characteristics of transmitter, antenna and propagation path geometry. However, too many factors hard to control and to determine exactly render this approach impracticable. An experimental approach leads to more reliable results. One can fairly safely assume that the electron density in the D-region is very low at night. This means that radio wave absorption is virtually absent then. A night-time measurement would therefore yield the required reference value, but there is a complication: Not only the D-region electron density disappears at night but also that of the E-region except when a sporadic E layer is present with a top frequency high enough to support propagation of the probing wave. Because intense night-time sporadic E is not a very common event, it might take some time after the beginning of a measurement until such events occur. We found that the following criteria for a night-time sporadic E-transmission were sufficient to derive reliable reference values of A_R.

1.) The event should occur after midnight.
2.) Uninterrupted propagation should at least last for three hours.
3.) The ionograms should show a blanketing Es layer and multiple reflexions.

Following these criteria, one obtains values for A_R which might have an error margin of about 3dB. Averaging of data of several events are considered necessary to obtain a reliable value of A_R. Due to the scarcity of intense night-time sporadic E events, it may take several months of continuous measurements until a reliable reference value is obtained. Because the antennas were designed to suppress the 1 x F mode, propagation of the probing wave via sporadic E is easily recognized without ambiguity as a strong increase of field strength at the receiver site, being much higher than during daytime. Because reflection of the wave takes place during night at some greater height than during daytime, a height correction should be applied. This correction was in our case very small.

4. RESULTS

4.1. Spatial validity of measurement

A measurement method of absorption which uses vertical incidence of the probing wave at the reflecting layer (A_1-methods) is obviously a local measurement. It has to be proven by additional experiments that the data so obtained represent the state of the D-region of a larger area. When the A_3-method is used, some smoothing is already obtained because the probing wave crosses the absorbing D-region at two different locations. These two locations are, however, at a fairly close distance to each other when the propagation path is of order 350 - 370 km (this distance is about the optimum for a probing wave frequency of 2500 - 2800 KHz), and the same arguments about spatial validity of the results of A_1 measurements are applicable to the A_3 method as well. This was one of the reasons why a network of absorption measurement circuits was installed in Spain. This network was supposed to yield experimental data which should allow to settle the arguments. It was found that the results of our A_3 absorption measurements were representative for a larger area. Fig. 4 shows as one example, results of measurements obtained during one winter on the propagation path Aranjuez (location of transmitter) - Balerma and Aranjuez-Arenosillo. Because the path Aranjuez - Arenosillo was slightly longer than that between Aranjuez and Balerma, the attenuation is slightly higher but one clearly notes that the results are well in parallel on both circuits. The correlation coefficient between the two sets of data was higher than 0.9. Such results allow to conclude that local variations in the state of the D-region are in most cases small against large-scale phenomena. Nevertheless, they are present.

4.2. Investigation of parameters used to quantify radio wave absorption.

In order to characterize the absorption measured over the day by a single figure, a number of parameters have been used in the past. Most of these parameters were derived empirically. One parameter which seems to be rather obvious is the mean noon absorption: One averages the measured absorption over a

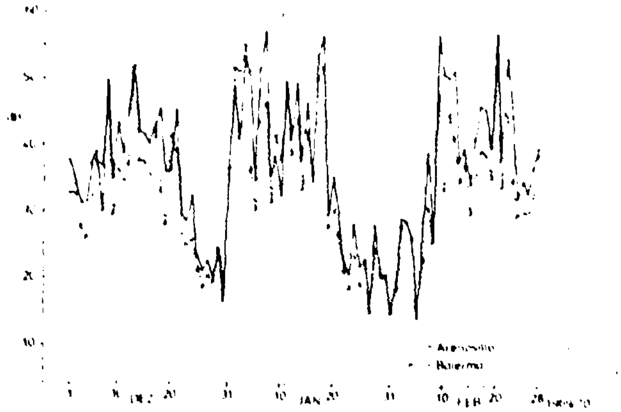

Fig. 4: Results of absorption measurements obtained on two propagation paths in southern Spain during winter 1969/1970.

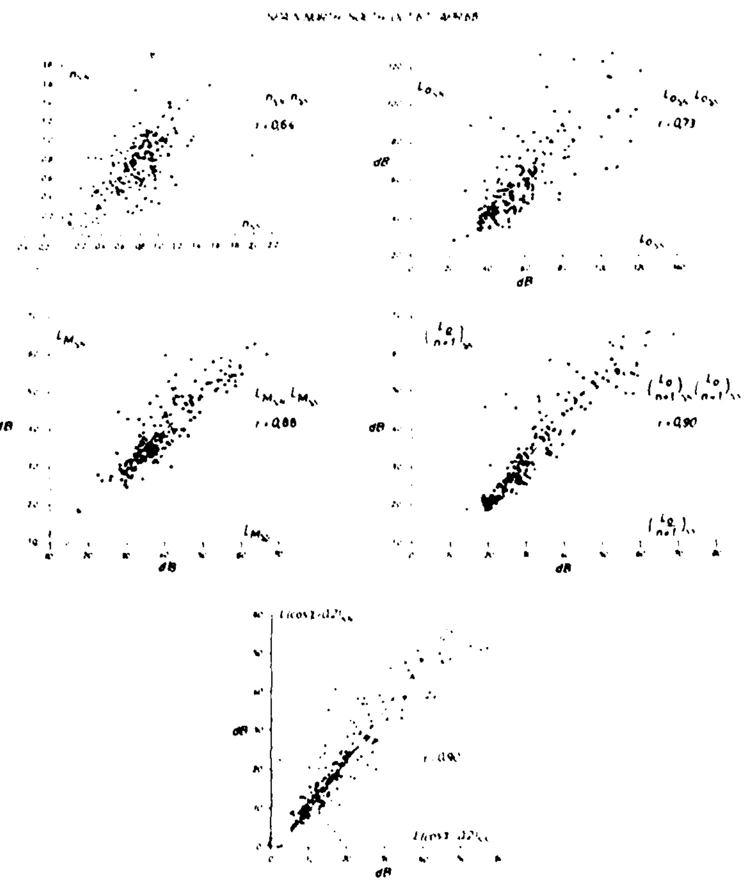

Fig. 5:

Correlation of different parameters used to characterize radio wave absorption. Parameters derived from measurements performed on the propagation paths Aranjuez - Balerma and Aranjuez - Alceda (see Fig. 1).

certain time interval around noon and takes this figure as being representative for the day. Empirical investigations, mainly performed in the U.K. have shown later that better results are obtained when one uses an extrapolated or measured value for a fixed solar zenith angle, other than for noon, for example: L ($\cos\chi = 0.25$). In further investigations, L ($\cos\chi = 0.2$) or even L ($\cos\chi = 0.1$) were used. But, at times when the solar zenith angle assumes such low values, the critical frequency of the reflecting layer is not much different from the operational frequency of the probing wave or is even lower. One would measure then mostly "deviative" absorption. To overcome this difficulty, one has to determine these parameters from the data taken during the whole day and has to use the approximation $L(\chi) = L_o \cos^n(\chi)$. Plotting $\log L(\chi)$ against $\log \cos\chi$, one obtains L_o and n either analytically by least square fit or just by drawing a straight line through the data fitted by eye and reads out the relevant value for L ($\cos\chi$) from this line. (The analytical method should be preferred because it is objective and excludes subjective errors).

A measure of merit for a given parameter can be obtained by a correlation between two sets of data obtained under identical experimental conditions but at different locations. For this purpose, two circuits were operated for one year between Aranjuez - Balerma and Aranjuez - Alceda. (See fig. 1). Both propagation paths were aligned as close as possible to the direction of the horizontal component of the magnetic field to favour propagation of the ordinary wave component.

Fig. 5 shows the results of a correlation of a number of parameters which may be used to describe the diurnal variation of absorption and absorption itself. They were derived from data gathered on the two propagation paths mentioned above. A winter period was selected because this season provides an "acid test": The diurnal variation of absorption is in general quite irregular during winter and the parameter which is most insensitive to this irregularity should be considered as the most suited one to describe a day in terms of absorption.

Fig. 5 shows that the $\cos\chi$-exponent "n" is least suited for this purpose. (It will be shown later that this parameter still yields some information about the state of the D-region). Best suited are the parameters L ($\cos\chi = 0.2$) and $L_D = \frac{Lo}{n+1}$ (this parameter shall be explained soon) because both parameters take into account the complete diurnal variation of absorption and not only part of it.

4.3. The parameter L_D

The judgement if a day should be called winter-anomalous or not is subject to considerable uncertainty when established parameters are used. With certainty, a day is not winter-anomalous when its absorption corresponds to the value to be expected from the seasonal variation of the Sun's zenith angle, but it seems to be at first difficult to establish the numerical value of this absorption. A parameter which eliminates the seasonal dependence of χ would solve this problem. The seasonal dependence of χ can be eliminated by integration of the measured absorption over cos χ. The integration yields a constant value

$$L_D = \int_0^1 L\ (\cos\chi)\ \ d\ (\cos\chi)$$

This integration seems to be at first of little practical value because measurements are taken over a limited variation of χ only and can therefore not be executed. But, fortunately, the diurnal variation of absorption can be very well described during summer by the $\cos^n$ law: $L\ (\chi) = L_o \cos^n \chi$. (See par. 4.5.1.) The correlation between approximation and real data is very good in the majority of all cases during this season, and when n and L_o are derived by least square fit from the real data, the integral can then be executed:

$$L_D = L_o \int_0^1 \cos^n \chi\ d\ \ (\cos\chi) = \frac{L_o}{n+1}$$

With some caution, L_D can also be determined from data obtained during winter.

Using this parameter, it is easy to decide if a day was winter-anomalous or not. The definition "winter-anomaly" includes in this case also a very irregular diurnal variation of absorption as being winter-anomalous and not only the amount of absorption alone. One could even use the correlation coefficient between approximation and real data obtained by the least square fit-evaluation of L_o and n as a measure for presence of the irregular type of

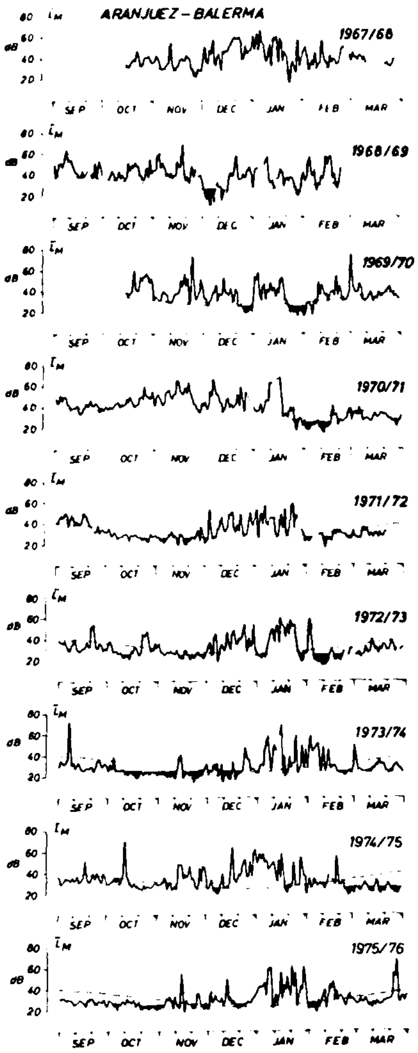

Fig. 6:

Variation of absorption described by parameter "mean noon absorption I_M" during winter 1967/68 to winter 1975/76. Propagation path Aranjuez - Balerma.

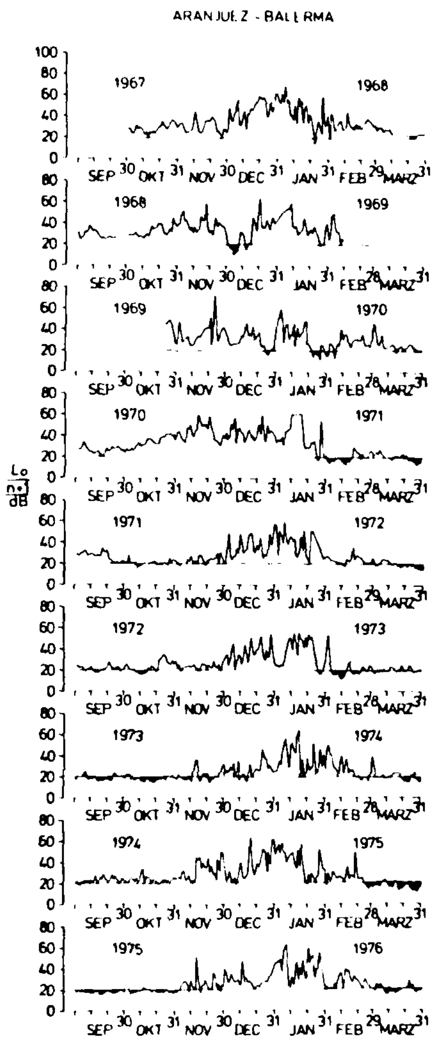

Fig. 7:

Variation of absorption described by parameter L_D during winter 1967/68 to winter 1975/76. (Propagation path Aranjuez - Balerma).

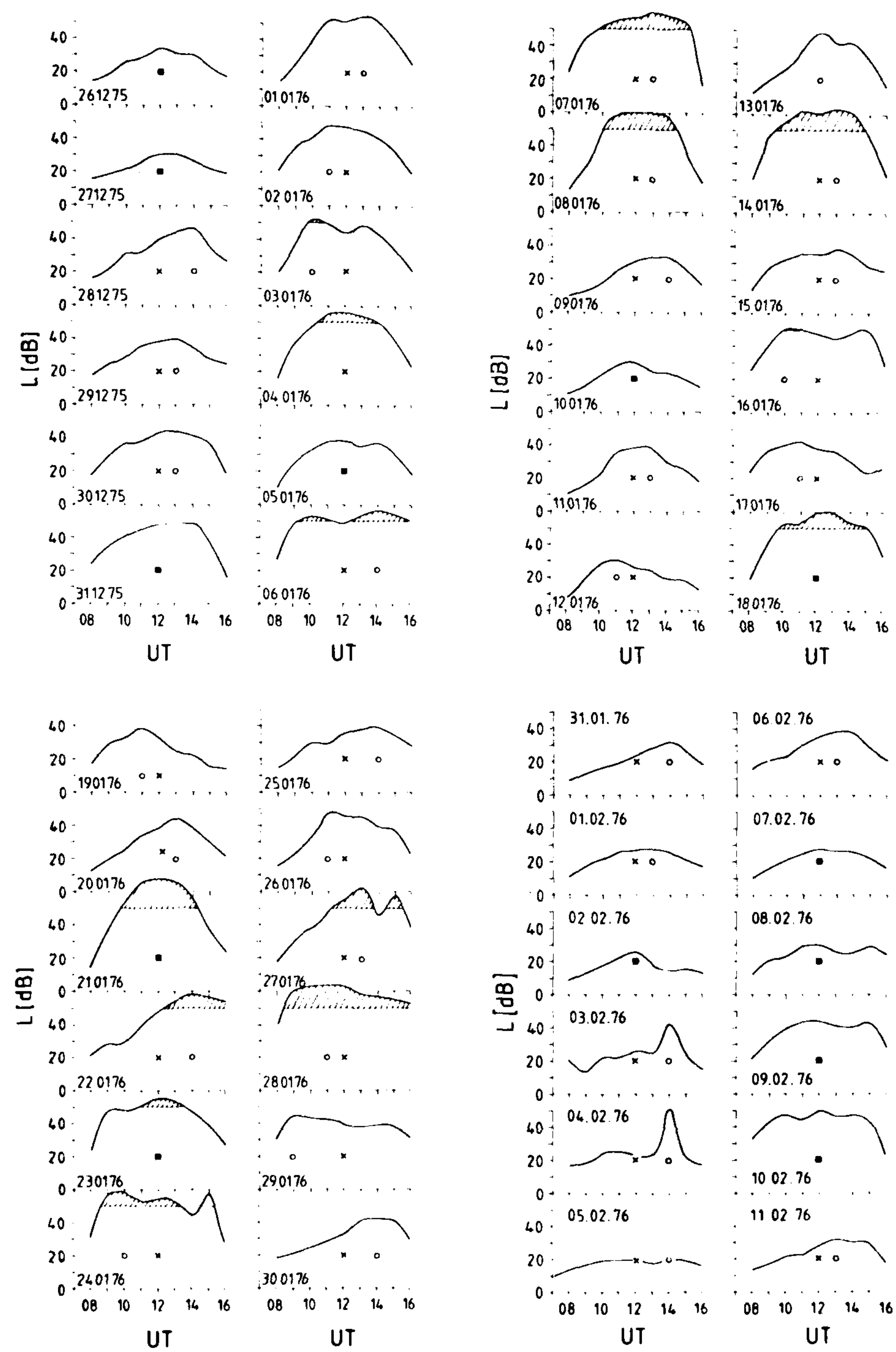

Fig. 8:

Diurnal variation of absorption measured during winter 1975/76.

winter anomaly, but this possibility was not evaluated in detail.

4.4. Short- and long-term periodicies of winter-anomaly

Fig. 6 and 7 shows the variation of absorption measured in several winter between 1967/68 to 1975/76. Fig. 6 shows the noon absorption, Fig. 7 the parameter L_D. One may note that the days on which absorption was very low (black-shaded in Fig. 6) correspond quite well to the value of absorption predicted by L_D determined in the summer season, but some periods seem to display a significantly lower absorption than expected. A good example is winter 1974/75: Absorption during March 1975 was by far too low. (This result will be discussed later in context with a discussion about possible causes of winter-anomaly).

Looking closer, one may notice a tendency of re-occurrrence of day with high absorption with a quasi-period of about 7 days. This period has been found on other locations also and might be considered as an established result though such periods are not clearly observed in all winters. Fig. 8 shows the diurnal variations of absorption which were measured during winter 1975/76 (it will be referred to this figure later) to illustrate how this quasi-periodicy of high absorption winter days looks like. Further, the results shown in Fig. 6 and 7 suggest a long-term variation of "intensity" and phase of winter-anomaly absorption. A refined analysis of the data was carried out in order to find out the amount of phase shift. The result is shown in Fig. 9, but "data noise" required filtering which might easily lead to a falsification of the result. Therefore, another approach was tried in order to determine if any phase shift was present at all. Using the approach of Appleton and Piggot [10] the winter period was divided into two sub-periods (1. September to 31. December and 1. January to 1. May) and the noon mean values and the parameter $L_D = \frac{L_o}{n+1}$ were averaged (both yield essentially the same). If a phase shift of winter anomaly is present at all, it should show up in a diagram in which the average absorption is plotted as an increase (or decrease) from the trend in the first half of winter and a corresponding decrease (or increase) in the second half-period. The result shows Fig. 10 and Fig. 11 the variation of the sunspot number during the observation period. One notes a trend almost parallel to the variation of the sunspot activity (which is to be expected because a similar relation was found for more northern latitudes [11] which is superimposed by two "humps" about four years apart.

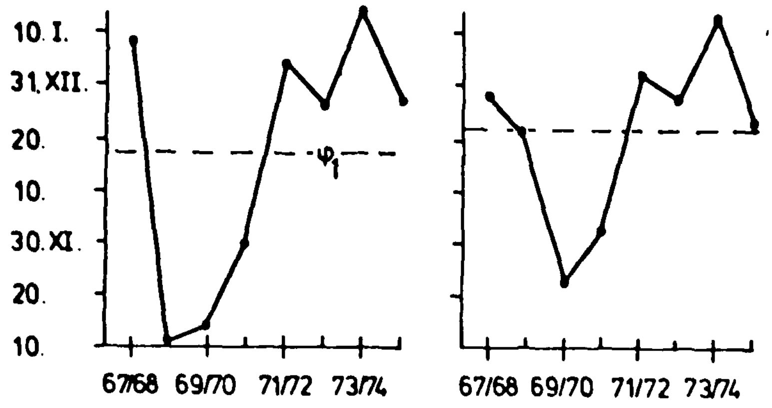

Fig. 9: Fourier analysis of data: Phase variation of maximum of winter anomaly.

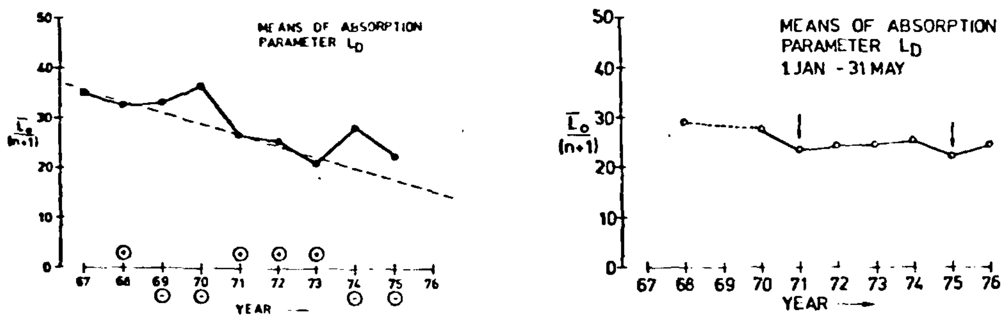

Fig. 10: Check of significance of result shown in Fig. 9. The winter season was divided into two parts (September to December and January to May) and the average value of absorption determined. The result confirms that winter anomaly started earlier and ceased earlier in winter and + - : sign of (significant) cross-correlation coefficients between vorticity area index of the troposphere of northern hemisphere and absorption (shift for maximum: between 2 and 4 days)

Corresponding "dents" are seen in the second half of the period (Fig. 10, (lower part). This means that the winter-anomaly effect started and ended earlier in these winters. Because (as shall shown later) the winter anomaly develops only when the water cluster ion regime has moved downwards into fairly lower heights, (which means that either the vertical transport of water vapour from lower heights into the D-region is cut off or the water vapour in the D-region is destroyed more rapidly by some process, the life-time of water vapour against photolysis is about 22 hours) and that the dominant source for D-region water vapour must be the troposhere (the oxydation of incident hydrogen from space as a second source of D-region water vapour [12] is probably less important but the oxydation of stratospheric methane may be an important source too) a cross correlation betweeen absorption and the area vorticity index of the northern hemisphere was attempted. A time shift for maximum correlation between two and four days was found. The correlation coefficients were at the threshold of significance but, surprisingly, were negative in the periods in which the "humps" occurred, and positive when the conditions were "normal". However, the period of observations was too short to decide if the quasi-four year period which the data suggest is real or not, but it is tempting to suspect that this period might be caused by a parametric oscillation of the D-region atmosphere induced by the quasi-biannal wind period in the stratosphere which, in turn, is triggered by the troposphere. Unfortunately, no sufficient wind data from the stratosphere and the mesosphere were available to verify this assumption. The question if this 4 year period is real or not must therefore remain open.

4.5. Diurnal variation of absorption

Another parameter which deserves some attention is the diurnal variation of radio wave absorption, but little use was made of it in the past due to certain difficulties of interpretation, as will be outlined later. It was already shown in the early days of ionospheric research that the diurnal variation of absorption follows a cos χ-law of the form:

$L(\chi) = L_0 \cos^n \chi$, χ = solar zenith angle, L_0: subsolar absorption.

Rawer [13] extended in 1943 the early works of Best and Ratcliffe and linked the cos χ- exponent "n" to the height extension of the absorbing layer and to the nature of electron loss processes (either recombination with positive ions or attachment of electrons to neutrals). Considering "thin" or "thick" absorbing layers and neglecting the influence of "deviative" absorption which was necessary at that time to render the problem treatable, he obtained cos χ - exponents between 0.5 and 2. This work of Rawer remained fairly unknown, because it was never published in relevant journals.

Nevertheless the experimental conditions of our radio wave propagation paths which we used to measure absorption met quite closely the conditions under which Rawer derived his cos χ -exponents, and it was considered worthwhile to investigate if the results of Rawer could be used as a guide to help interpretation of our measurements.

As was mentioned before. not much use has been made of the cos χ- exponent "n" in the past for several reasons. First, the numerical value of "n" depends critically upon the design of the circuit and is, by this, not an invariant. A demostration of this was, for example, given by Schwentek and Timpe [14]. They have shown that the numerical value of the cos χ-exponent is different when the wave is reflected at the E- or at the F-layer. This is due to the influence of deviative absorption, that is the contribution from height levels in which the electron density is high enough to reduce the group velocity of the wave appreciably, leaving the electrons which oscillate in the electric field of the wave more time to loose their energy by collisions. Therefore, if one discusses seasonal variations of "n", one should confine this discussion to results obtained on the circuit under consideration. Comparisons between different circuits are possible if they are similar or based on relative changes of "n" with season.

A further rather important reason for the reluctance to use the cos χ-exponent as a parameter o describe changes in the D-region of the ionosphere is that the cos χ-exponent "n" can be dermined with less accuracy than any other parameter. Most data are collected at a time when the solar zenith angle changes little with time (near noon). A small scatter in the data influences the numerical value appreciably as does an incorrect reference value of A_R (see par. 3.1.). One needs a fairly high accuracy of measurement but obtains only a parameter which has a large margin of error. This was illustrated by Fig. 5 were the results obtained on two circuits of about identical design are correlated.

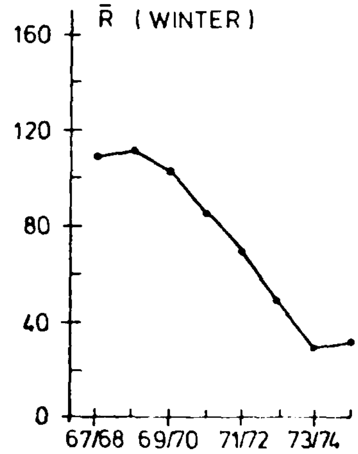

Fig. 11: Variation of average sunspot number $\bar{R}$ during observation period winter 1967/68 until winter 1974/75.

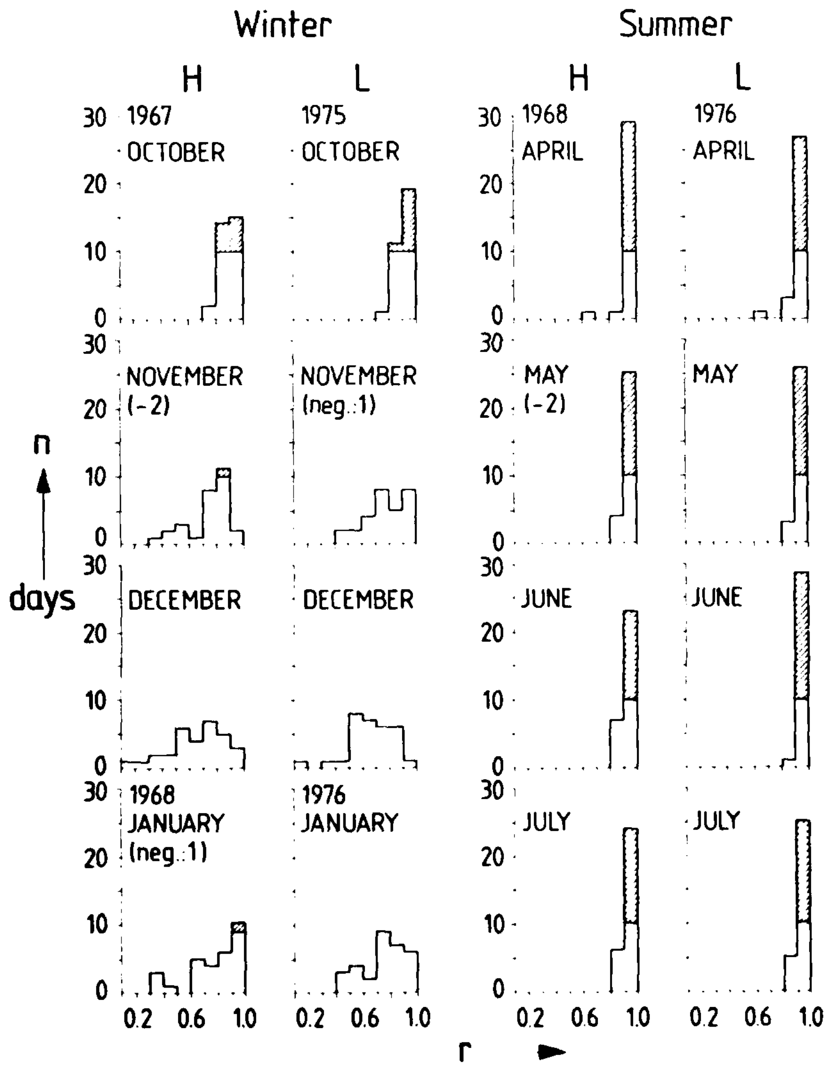

Fig. 12: **Histograms of correlation coefficients between least square fit and real data of diurnal variation of absorption (Aranjuez-Balerma). Intervals 0.11..0.2, 0.21...1.0. All data.**

H: high, L: low activity of the sun.

Further, the diurnal variation of absorption is often not symmetrical to noon, especially during winter. The maximum of absorption is then often shifted into the afternoon or (in some cases) the maximum is reached in the forenoon. In order to take into account of this, the cos χ-exponent "n" is often determined separately for forenoon and afternoon. This empirical procedure, though used quite often, leaves something to be desired from a physical point of view.

4.5.1. Validity of the $\cos^n \chi$ - approximation

This puts up the question if the $\cos^n \chi$--approximation is a meaningful approximation at all and if it can be applied sensibly. Basically, the $\cos^n \chi$-approximation assumes quasi-steady-state conditions. This presumption is at least not true during the winter season. Fig. 8 illustrates this.

One way to answer this question is to determine the cos χ-exponent "n" and the subsolar absorption L_o from the measured data by least-square fit methods and to correlate the measured data with the relevant values of the approximation so obtained. The correlation coefficient is then a measure of merit how good the approximation fits. This was executed for data obtained at the beginning of the measurement period (1967/68, high sun activity) and for the same months (October to January and April to July) at its end. (1975/76, very low activity of the sun). Fig. 12 shows the histograms of the correlation coefficient. The intervals for the correlation coefficients were chosen as 0.11..; 0.2.; 0.21...; 0.3; ... 0.81.. 0.9; 0.91.. 1.0. The result allows to draw the following conclusions:

1.) The agreement between real data and approximation is very bad during the winter months when winter-anomaly is present. This means that periods other than the diurnal variation of the sun's zenith angle dominate the diurnal variation of absorption, and that these periods are not always synchronized to the variation of the sun's zenith angle.

2.) The agreement between approximation and real data is good to excellent during the summer months. The correlation coefficients for real and approximated data drop then rarely below 0.9 (see Fig. 12).

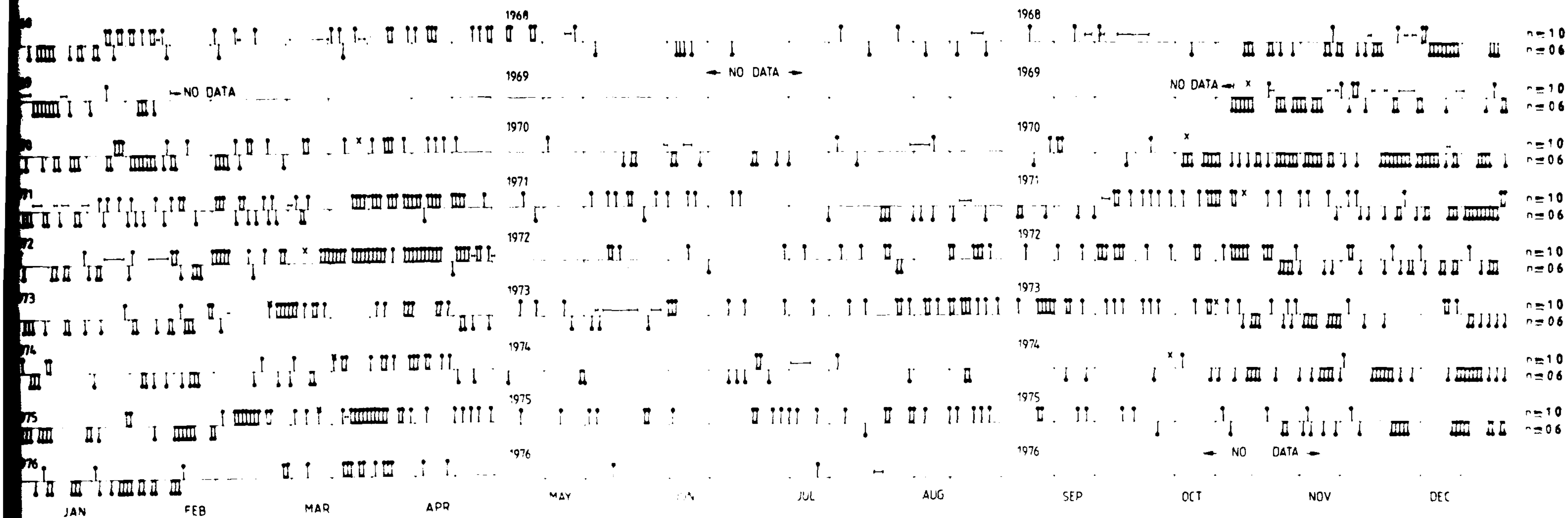

Fig. 13: Seasonal distribution of days with n $\leqslant$ 0.6 and n $\geqslant$ 1.0 during the measurement period 1967 - 1976. Crosses: end of winter circulation over East Germany (after Sprenger).

This suggests that "irregular" tides are then either absent in the D-region of the ionosphere or so small that they are completely masked by the diurnal tide caused by the variation of the solar zenith angle. Assuming that winter anomaly is caused by transient coupling of the D-region atmosphere and lower heights (this possibility was discussed in the literature quite extensively), one is tempted to say that this kind of coupling does not exist during the summer months because the diurnal variation of absorption is so regular and the day-to-day fluctuations of parameter L_D are relatively small. We shall see in par. 4.5.2. that this conclusion might not be valid in full.

4.5.2. Seasonal variation of the shape of diurnal variation of absorption.

4.5.2.1. "Shallow" diurnal variations.

The shape of the diurnal variation of absorption may change from day to day and with season, but some trends can be easily recognized: Rather "shallow" diurnal variations ($n < 0.5$) were more frequent on our propagation paths during winter than "peaky" ones which are described by a larger n (> 1.0). The disturbation of days observed during our measurement period (1968 - 1975) is shown in Fig. 13 for the individual years and is summarized in Fig. 14 for the whole period of measurement. It shows clearly a maximum for the winter months and a minimum for summer. It might be possible that the slight peak in frequency of occurrence found for August is real because we observed a marked increase of day-to-day fluctuations of L_D, L_M (average noon value) or L ($\cos \chi = 0.2$) in all years during this month compared to that found during other months of the summer season. As Fig. 8 showed, the low "n" observed on our circuits during winter was often caused by a rather irregular diurnal variation of absorption. Despite Fig. 8 presents data obtained during one winter only, it can be taken as the typical result because similar results were obtained in all winters of the observation period.

On other propagation paths, which maybe located either more in the norths or use propagation path lengths and operational frequencies different from those used for our measurements, things may be different: This illustrates Fig. 15. (After Schwentek et al [16]). It shows the seasonal variation of "n" for absorption measurements performed at Lindau (Germany). It is claimed that large "n" were more frequent there during the winter months than during the rest of

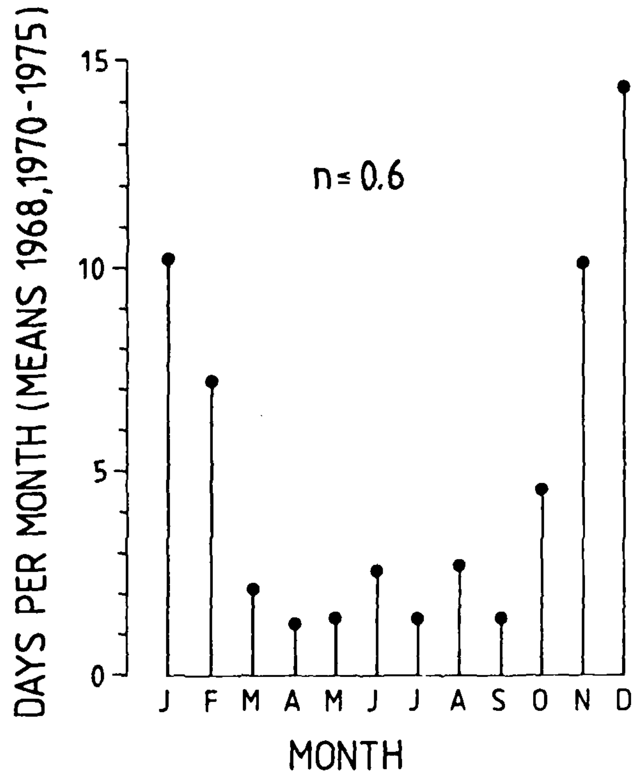

Fig. 14: Abundance of days with n < 0.6 during the observation period 1968 - 1975 (years in which measurements were not performed throughout the whole year are omitted.

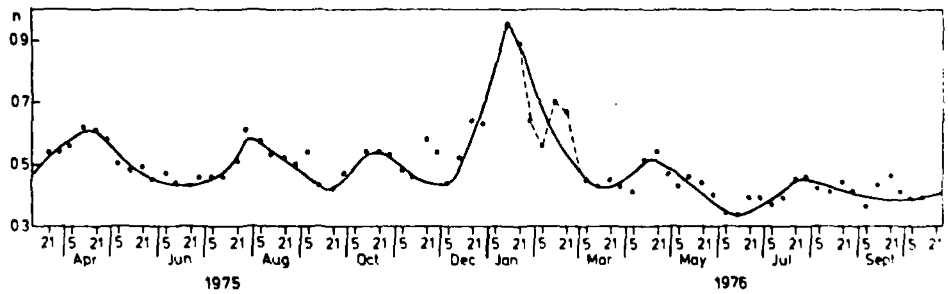

Fig. 3. Seasonal variation of an average value of exponent *n*. The plotted data were obtained from daily *n* values; $f = 2.61$ MHz. For every 15 or 16 days, starting with the period 5-21 March 1975, and proceeding in steps of about 8 days, the lower and upper quartile values were determined, and then the mean values of all the *n* data between the 2 quartile values were calculated. A similar result can be obtained also using the median values of the quoted periods. The curve was drawn tentatively to show the wave-like variation in the seasonal behaviour of exponent *n*; the mean period obtained from the plot is about 96 days. Note that the maximum in winter occurs at 15 January, that is about 4 weeks delayed related to the winter solstice

Fig. 15: Seasonal distribution of n during 1975/76 on a propagation path in central Germany (after Schwentek et al, [16]).

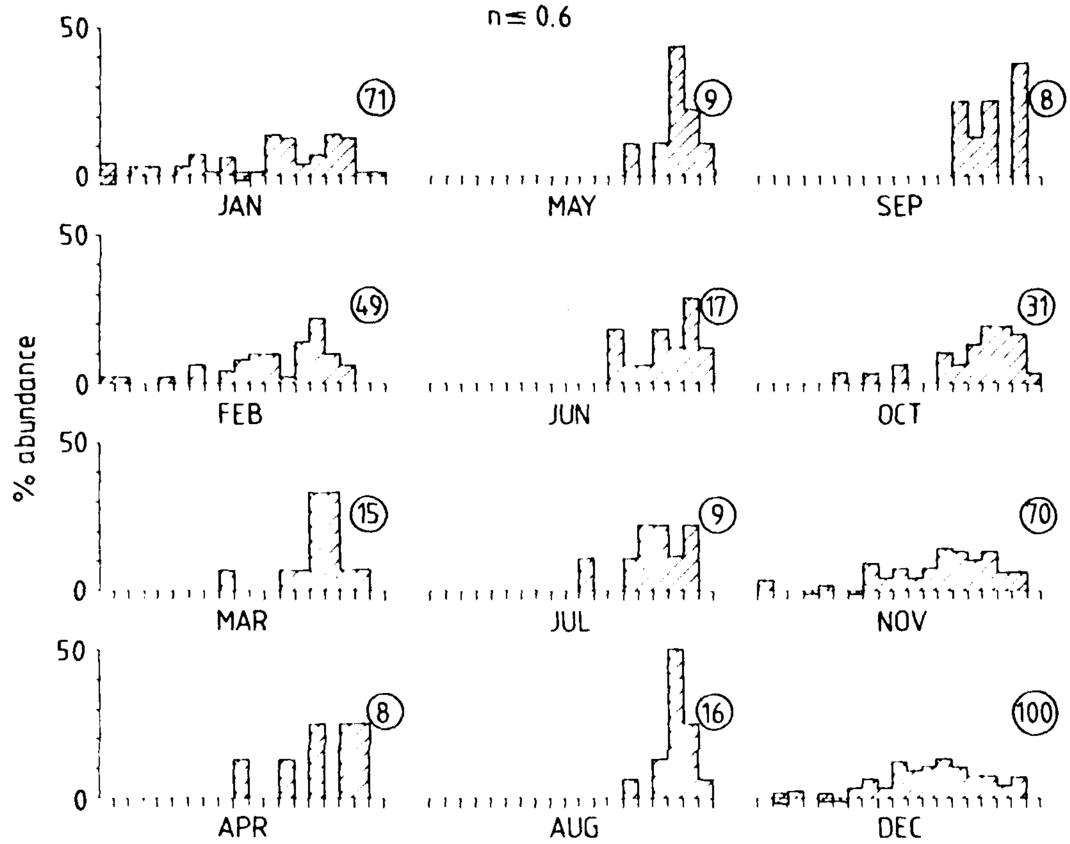

Fig. 16: Histograms of the correlation coefficient between least square fit and real data for days n ≤ 0.6. Measurement period 1968, 1970 - 1975. Encircled figures: Total number of events.

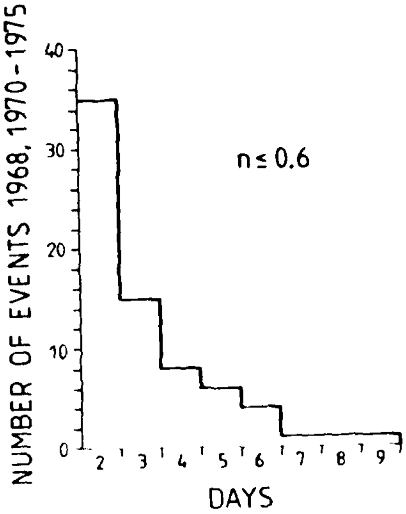

Fig. 17: Histogram of persistence of days with $n \leqslant 0.6$.

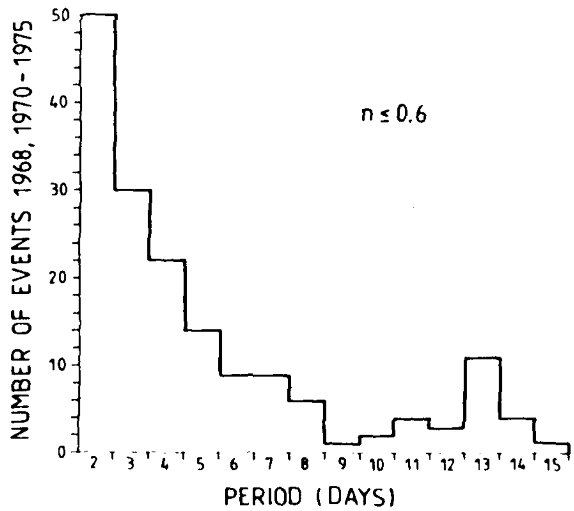

Fig. 18: Histogram of re-occurrence of days with $n \leqslant 0.6$.

the year. Unfortunately, the raw data from which the results shown in Fig. 15 were derived were not available to the author, and the data presented (which represent some kind of running averages) do not allow a detailed analysis how the result was achieved. A large "n" is indeed often linked to high (winter anomaly) absorption while the reverse is mostly the case for the other months as shall be shown later. This comparison may illustrate the difficulties which one encounters when dealing with diurnal variations of absorption. In this context, it may be of interest to investigate the validity of the $\cos^n \chi$-approximation for diurnal variations described by a low "n". Taking again the correlation between real data and least-square-fit approximation as the figure of merit, one obtains Fig. 16, which shows histograms of the correlation coefficient found for the relevant months of the measurement period 1968, 1970 - 1975. The agreement between approximation and real data is not very satisfying, especially during winter, and one might suspect that "deviative" absorption has played an important role for this result. Our in-situ measurements of electron density however, which we performed at El Arenosillo in parallel to absorption measurements have shown us that the "deviative" contribution to absorption was, on average, a more or less constant fraction of the measured amount of absorption. This result allowed us to interprete with some confidence irregularities in the diurnal variation of absorption in terms of transport phenomena.

Fig. 13 shows that the days on which a "shallow" diurnal variation of absorption was measured have a tendency to occur in groups of days and have a certain tendency of re-occurrence. Fig. 17 shows the histogram of persistence of such days observed during the whole period 1968 - 1975. Fig. 18 shows the histogram for re-occurrence. To these figures shall be referred to later (par. 4.5.2.3.)

4.5.2.2. "Peaky" diurnal variations

In the preceding paragraph, the seasonal distribution of "shallow" diurnal variation of radio wave absorption was discussed. It was stated there that "shallow" diurnal variations are quite often a manifestation of a rather irregular variation of absorption over the day. In contrast to this, "peaky" diurnal variation are in most cases rather symmetrical to noon and seem to be nothing peculiar until one looks for their seasonal distribution. Before doing that, one should look how good the $\cos^n \chi$-approximation (which assumes quasi-steady-state conditions) fits the real data for such days. Again, the correlation coefficient between real data and least-square-fit approximation was taken as figure of merit and the individual months of the measurement period 1968 and 1970-1975 were considered. Years in which

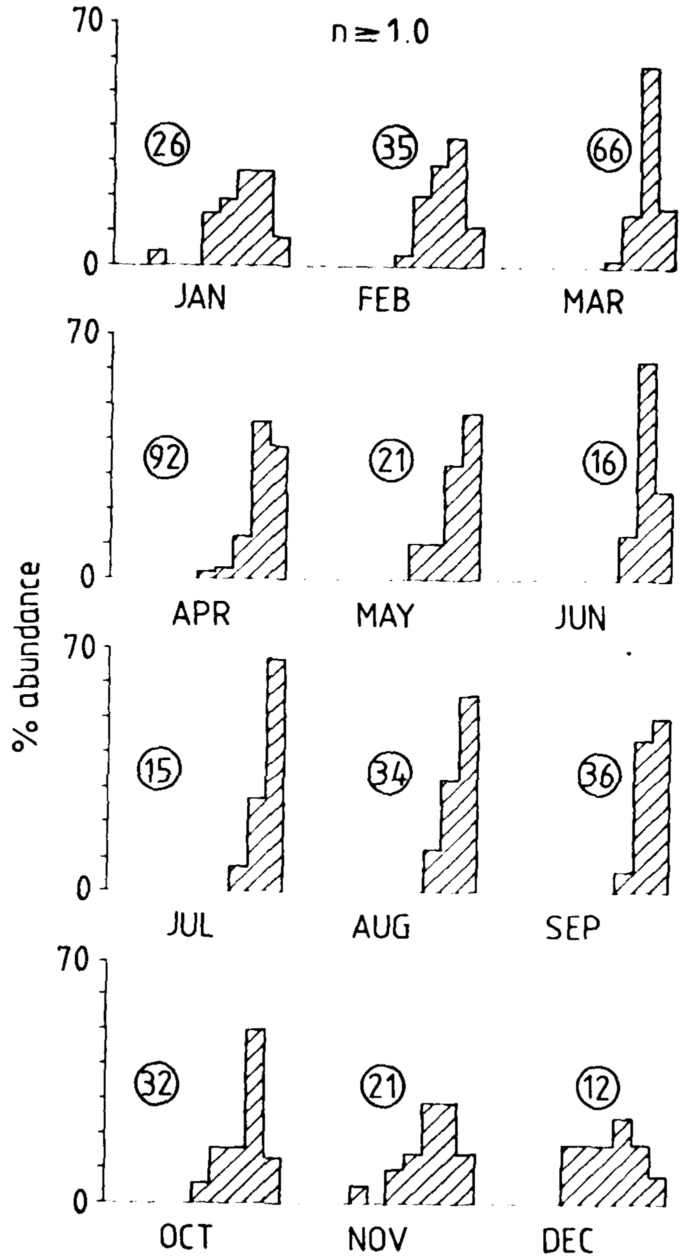

Fig. 16a

Histogram of correlation coefficients between least square fit and real data for days $n > 1$. Measurement period 1968, 1970 - 1975. Encircled figures: total number of events, This figure corresponds to Fig. 16 (same division of intervals. See text).

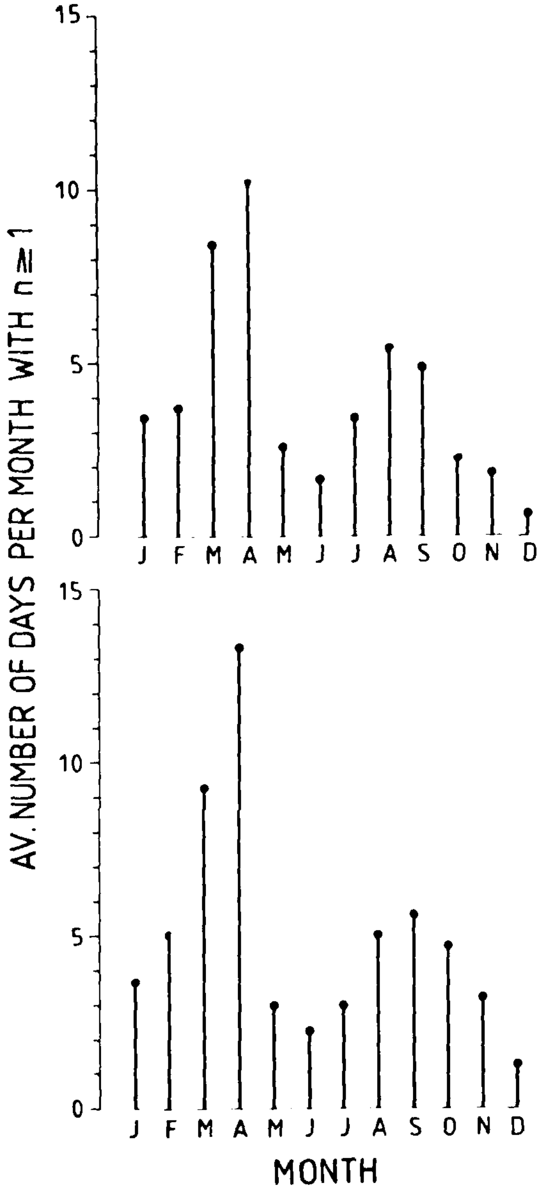

Fig. 19: Abundance of days with $n \geqslant 1.0$ during the observation period 1968 - 1975. Years in which measurements were not performed throughout the whole year are omitted.

Top: Result obtained when 1972 data were not considered.
Bottom: Results obtained when 1972 data were included.

observations were made only during a few months (1967, 1969 and 1976) were omitted. The result is shown in Fig. 16a. A comparison with Fig. 16 shows that solar control was by far much better for days which had a "peaky" diurnal variation of absorption than for those which had a "shallow" one. One notes further that the steady-state-approximation fitted quite well during the summer months but was less valid during winter.

It was shown in Fig. 13 how such days were distributed over the observation period 1968 - 1975. Each year "has its own individuality" but one notes that such days seem to be more frequent during Spring and Autumn and that they have a tendency to occur in groups of days which are superficially similar to that of winter anomaly observation and to that of groups-of days with low "n" (which, as was said before, is about synonymous). This "grouping structure" was very well pronounced during Spring 1972. The histogram Fig. 19 summarized the results of the observation period and shows clearly that such days are indeed most frequent during the equinoxes (Spring and Autumn). The distribution shows a clear minimum for mid-winter and mid-summer.

Fig. 20 shows the histogram of persistence, Fig. 21 shows the histogram of re-occurrence.

4.5.3. Comparison

Comparing Fig. 20 with Fig. 17 (persistence) one notes that they are not very much different. Groups of days which are longer than 5-6 days are fairly rare. Things are different if one compares Fig. 18 with Fig. 21 (tendency of re-occurrence.) The probability that a "shallow" or "irregular" diurnal variation is also present on the following day is much higher than it is the case for a "peaky" diurnal variation. The "peaky" diurnal variation of absorption seems to occur more often as an isolated event. Its tendency of re-occurrence is also different: The histogram has peaks near 4-6, 8-9, 11 and 15 days which might be real while "shallow" diurnal variations do not show this except a small peak near 13 days. These results seem to suggest that processes to which the atmosphere responds with a "peaky" diurnal variation of absorption have a shorter time scale than those which cause an irregular or "shallow" diurnal variation of absorption: Taking the tendency of re-occurrence, it seems that it takes a longer time to develop conditions which produce "shallow" or irregular diurnal variatons of radio wave absorption than is needed to develop "peaky" ones.

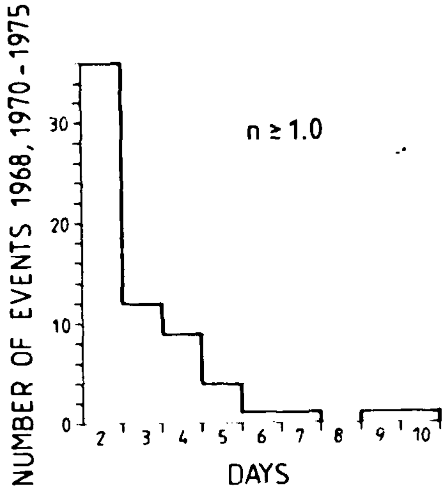

Fig. 20: Histogram of persistence of days with n $\geqslant$ 1.0.

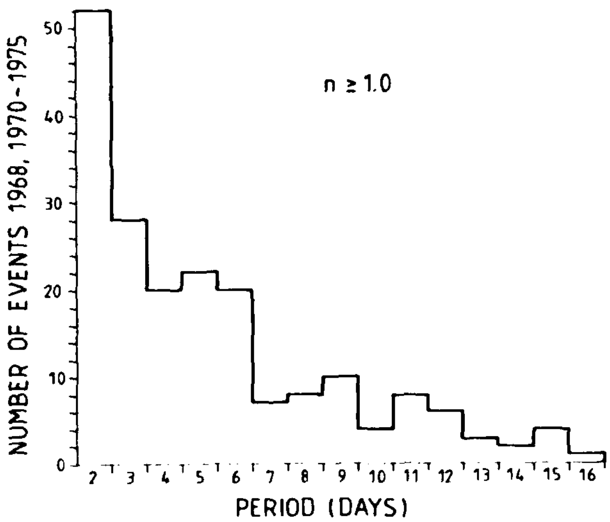

Fig. 21: Histogram of re-occurrence of days n $\geqslant$ 1.0 .

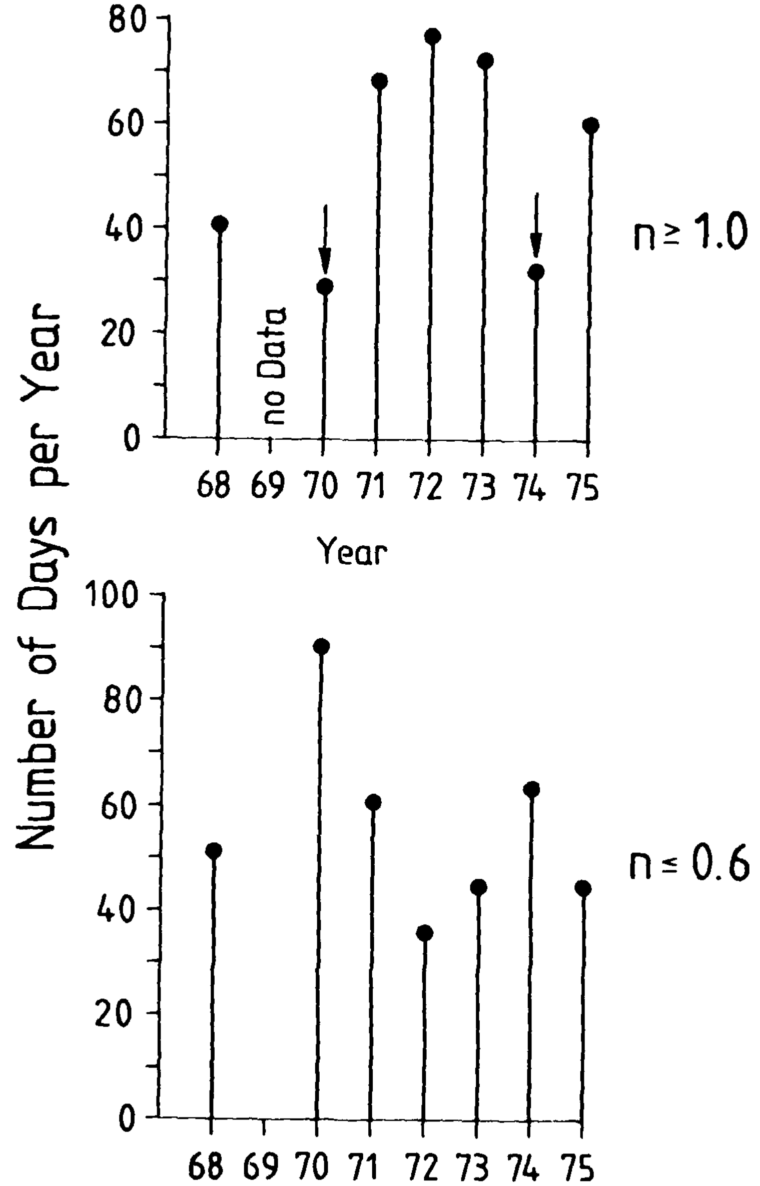

Fig. 22: Total number of days of a year with n > 1.0 found during the observation period 1968, 1970 - 1975. Arrows indicate years in which winter anomaly occurred "earlier" (shift of maximum)

Fig. 23: Total number of days of a year with n < 0.6 found during the observation period 1968, 1970 - 1975.

Before discussing what might cause the different shapes of diurnal variation of absorption, we should have a look at the total number of days of a calendar year for which "n" was "large" ($n > 1.0$) and "small" ($n < 0.6$.)

These figures are presented in Fig. 22. They are variable from year to year. It might be of interest to note that the number of days on which "n" was large ($n > 1$) was significantly smaller during the years in which a shift of winter anomaly occurrence towards an earlier date was observed (see Fig. 10). The number of days on which the diurnal variaton of absorption was "shallow" was then larger as might be expected. The total number of days on which the diurnal variation of absorption was either "shallow" or "peaky" was different in different years, (Fig. 23) but there seems to be an indication for an inverse relation between the two numbers. This is shown by Fig. 24 in which the number of days per year with "shallow" variation is plotted against the number of days with "peaky" ones. This correlation is however, not very significant ($r = 0.65$, $n = 7$, significance 88%): The observation period was to short to yield a significant result.

4.5.4. Probable causes for variations in shape of diurnal variation of absorption

The diurnal variation of absorption is primarily caused by the diurnal variation of the solar zenith angle. This variation causes a change of ionization at all levels of the ionosphere, and the equilibrium density of free electrons is controlled by production and loss rate of electrons. This electron loss rate is an involved function of ion-chemical processes. It is therefore common practice to describe the electron loss by an "effective" electron loss rate. One model which has turned out to be rather successful is the two-ion model of Haug and Landmark [18]

When we look at the data presented in Fig. 8 (diurnal variations of absorption during winter 1975/76) we may suspect that the irregular type of diurnal variation of absorption might be caused by dynamic processes (advection and convection) which changes the height distribution of electron density by transport of minor constituents. These change the effective electron loss rate and the production of electrons, and, indeed, the results of several investigations have shown that horizontal and vertical transport has some influence on both the shape of diurnal variation of absorption and on the amount of absorption itself. It was shown in papers published by Geller [19] , Manson [20] [21] [22]

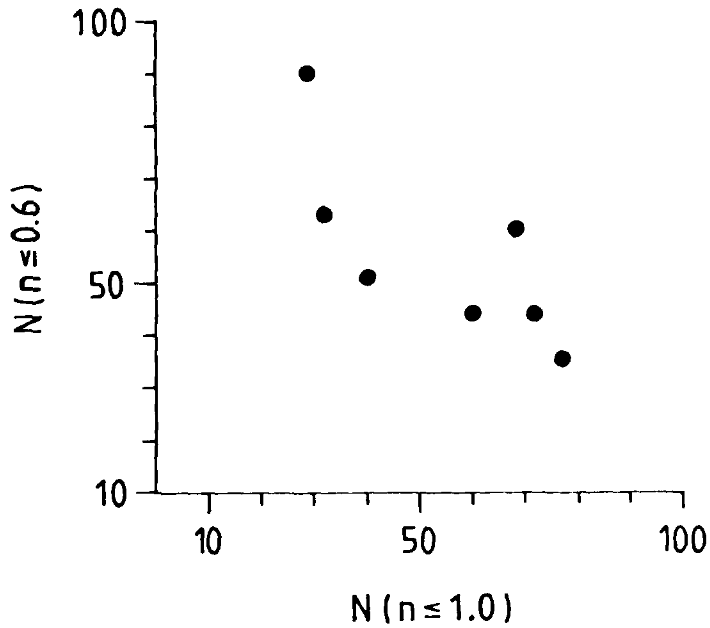

Fig. 24: Correlation between number of days n > 0.9 and number of days n < 0.6.

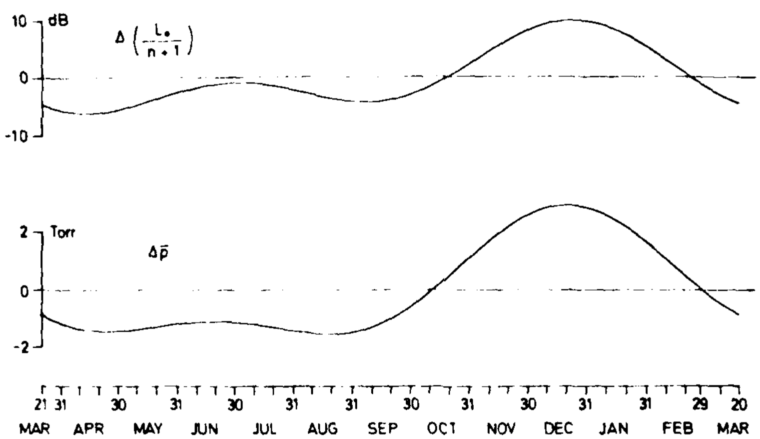

Fig. 25. Seasonal variation of changes of ground pressure and absorption in southern Spain.

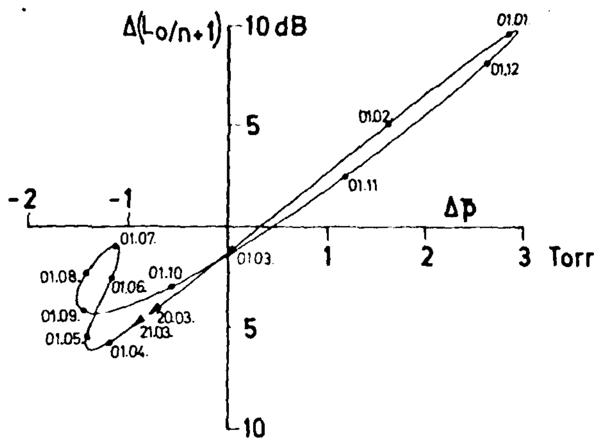

Fig. 26: Correlogram between seasonal variation of absorption and changes of ground pressure in southern Spain.

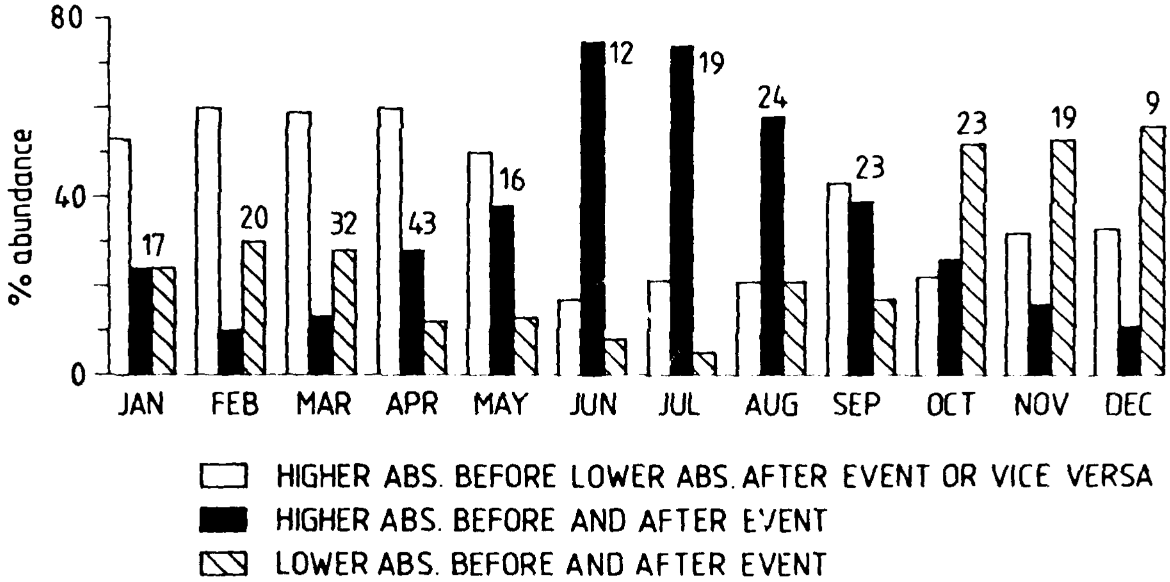

Fig. 27: Relation between absorption measured on day before and after a day (or group of days) with large "n". Fig. 27 shows that the physical meaning of large "n" changes with season. During summer it means that absorption is in most cases lower than the day before and the day after such an event.

Rose et al [23] [24] . Rees et al [25] (this list is by no means complete) that absorption is related to wind changes. It was also concluded that a coupling between the D-region atmosphere and lower levels exist during the winter season but should not occur during summer. A result which supports this conclusion was obtained when the variation of radio wave absorption in the D-region was correlated with the variation of atmospheric pressure measured on the ground

[24] . Fig. 25 and 26 show the result of this investigation. Absorption variation from the mean and pressure variation from the mean pressure were on average in phase during winter, spring (until April) and in late autumn, but was out of phase during summer. This holds true only for the long periods year and half-year- periods) but no significant result was obtained for higher frequencies because the "noise" of data is too high.

The results shown in Fig. 13 and 19 (seasonal distribution of days with "peaky" diurnal variation of absorption) suggest that this seasonal distribution may also be linked in some way to coupling effects between the D-region and lower (or higher?) levels of the atmosphere because such days are observed mainly during the season in which the winter circulation changes over to summer circulation. Further, it is well known that this transition is more violent during spring than during Autumn were this transition is more gradual. Fig. 19 shows that days with n > 1 are most frequent during Spring. Informations about winds in the upper D-region atmosphere (90 - 100 km but not for lower levels) can be obtained through ground-based drift measurements made with long or medium waves more or less continuously during night. Such measurements were excecuted over a long period of time in East-Germany. The distance between southern Spain (were we performed our measurements) and East-Germany ist about 2000 km, and it seems to be at a first sight problematic to refer to these data. However, one can argue that the reversal of a planetary circulation is not a local effect but affects a large area more or less simultaneously. Further, one has reason to assume that this change is a matter of at least a few days and not an effect which occurs within a few hours.

Fig. 13 shows that a very pronounced "grouping of days" with n > 1 occurred during Spring 1972 which was not found in other years of the observation period. If the increase of abundance and of grouping of days with "peaky" diurnal variation of absorption is in some way linked to the transition from winter to summer circulation ("Spring Anomaly") one should expect that something peculiar had happened with the circulation during spring 1972. This was indeed the case: "Spring 1972 was peculiar in that the winter circulation ended for the first time since 1958 at middle of March. In contradiction to all experiences obtained during 20 years of measurement, the spring circulation which started then was interrupted from 30. March to 14. April.

A circulation was then observed similar to that which was present during winter-time stratwarms, e.g. that of 29.1.-11.2.72 and also that of 1967 (31.1. - 13.2.). The temperature at 10 mb was -20°C over east Siberia. The spring circulation ended on 27.4.72"(R. Schminder, personal communication). This information refers to a height level between 90 and 100 km were the sounding frequencies of 185 KHz and 272 KHz used for the wind measurements were reflected during nighttime. No other informations about wind changes in lower heights were available. The full story what happened during this period remains therefore unknown. But if one enters into Fig. 13 the dates on which the winter circulation ended over central Germany, one finds (within a certain margin) that the grouping of days with high "n" began to increase in frequency after that date during spring and ended after the beginning of winter circulation in autumn. After that date, groups of days with low "n" were observed after or short before the winter circulation began over central Germany. Taking into account that the date on which the winter circulation ended or began is not always very well defined (there are almost always days before and after that date which show "summer" resp. "winter" circulation) it seems to be fair to assume that the grouping of days with "high n" is closely linked to the change of circulation and the grouping of days with "low n" is a winter phenomen.

A change of wind speed and wind direction at 90 km might cause a re-distribution of electron density with height near this level. This re-distribution can be caused by vertical movements (either turbulent or subsidence) or, more or less equivalent, by a change of air density. This change of air density may cause an increase of electron production in lower heights but not necessarily may cause a change of ion composition in the D-region. Because absorption of the probing wave depends upon the product between electron density N_e and electron collision frequency with neutrals ν_{en}, the absorption contributions from lower heights becomes then more important, but the loss rate of electrons is higher in lower heights. This causes a more rapid decay of electron density in the afternoon and a slower build-up of absorption during the forenoon which results in a "peaky" diurnal variation of absorption. The total amount of absorption may also be somewhat lower on such days compared to that found on "normal days" but this need not to be true in all cases and has to be checked.

4.5.5. Relation between shape of diurnal variation and amount of absorption

The result of this check is presented in Fig. 27. This check was done in the following way: The day with event " n > 1" was taken as key day and the amount of absorption measured on the day before and on the day after the event was compared with that measured on the key day. When the key day was the beginning of a group of days with n > 1, the day following the last day of this group was considered as "day after the event". By this, the events could be classified into three groups: The first group contained events for which absorption on the preceding day was higher than on key day but lower on the day following the event (or vice versa). The second group comprised events for which the amount of absorption was higher than on key day on preceding and following day, and the third group comprised those events on which absorption was higher on key day than on the preceding and the following day. In order to obtain a clear picture, the years for which the observations were incomplete (1967, 1969 and 1976) were omitted.

Fig. 27 shows clearly that the supposition that absorption is lower compared to that measured on the preceding and the following day when the diurnal variation is "peaky" holds true only for the summer months. The number of "undecided cases" is then also a minimum. During October, November and December the meaning changes: in about 50% of all cases, absorption is increased compared to that measured on the preceding and the following day. This result suggests that the physical processes which cause a "peaky" diurnal variation of absorption are not the same during summer and during winter. During summer, a temporal reduction of EUV and soft X-ray radiation may cause a reduction of electron density near the 90 km level, but leaving the ionization unchanged at lower levels below 80 km. This will cause a "peaky" diurnal variation. In winter, an increase of $O_2\,{}^1\Delta g$ will produce more O_2^+ ions and, by this, a higher electron density which causes "winter anomaly". The role of $O_2\,{}^1\Delta g$ as one of the minor constituents of the D-region ionosphere which eventually causes winter-anomalous absorption was at least partly eludicated during the Western European Winter Anomaly Campaign which took place Winter 1975/76. [25] . $O_2\,{}^1\Delta g$ has a shorter lifetime than nitric oxide. It is generated during day by radiation of the sun and is destroyed after sunset. The diurnal variation of absorption will therefore follow the variation of the solar zenith angle quite closely. Because substantial amounts of $O_2\,{}^1\Delta g$ are produced in the D-region predominantly at lower zenith angles of the sun (near noon) the diurnal variation of absorption will be described by a larger n. These results may explain why no significant relation between the shape of diurnal variation and amount of absorption has been found in the past: The physical meaning changes with season, and if one considers a year as a whole, no significant result will be obtained.

5. Verification of results

The results presented so far have been obtained from measurements which were performed in Spain. They can be criticized as being accidental until similar results are obtained from data collected in higher or lower latitudes evaluated in the same way as the data obtained in Spain.

The only data which are available for such an analysis were those gathered on the propagation path Coburg-Graz (Austria). The same type of technical equipment was used on this propagation path (receiver, transmitter, antennas) but the path length was longer than those used in Spain (500 km). On long propagation paths, the numerical values for "high n" and "low n" (in the sense considered here) are different. They have to be determined experimentially from the bulk of data. It was found that a cos χ -exponent $n > 0.6$ was about equivalent to $n > 1$ which was selected for the propagation paths in Spain. Because of the larger path length, the signal strength at the receiver site at Graz was much lower than in Spain. This caused a detoriation of the signal-to-noise ratio and rendered the results to be less accurate than those obtained in Spain. The analysis was therefore confined to the case of "high n" which had turned out to describe days on which the diurnal variations followed the variation of the solar zenith angle best. Unfortunately, only 18 months of observation (1 Jan. 1975 - 1 Dec . 1976, 1. Jan. 1976 to June 1976) were available for analysis. If the distribution of days with "high" n is really linked in some way to changes in dynamics at or near D-region heights, and if the result presented in Fig. 19 is of significance, one should obtain similar distributions of abundance of diurnal variations of absorption for both propagation paths, Spain and Germany/Austria. This was indeed the case,* but Fig. 28 and 29 shows, that the maximum of occurrence of such days with large "n" was about a month later during Spring on the propagation path Coburg-Graz than it was observed for Spain. This was the case in both years, 1975 and 1976. Further, a grouping structure of such days were also seen in the

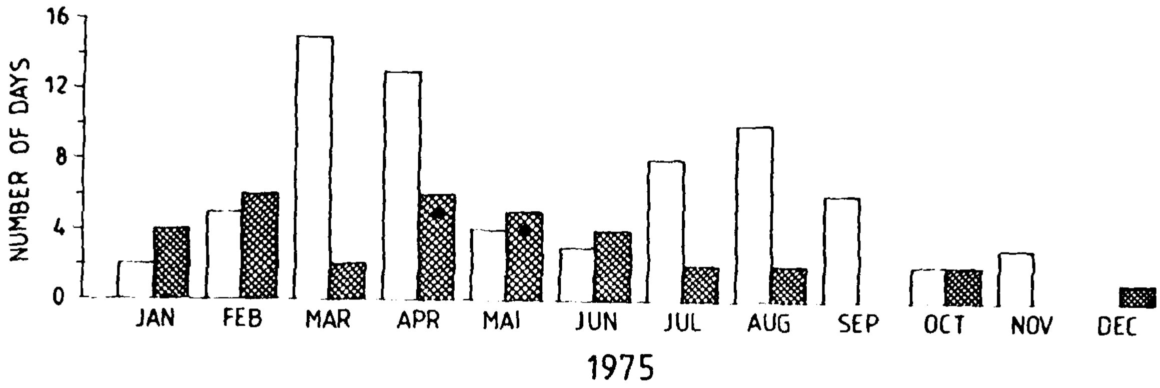

Fig. 28: Abundance of "peaky" diurnal variations (n > 1) on the propagation path Aranjuez - Arenosillo (Spain) and on the propagation path Coburg-Graz (n > 0.6) (shaded) in 1975 and 1976.

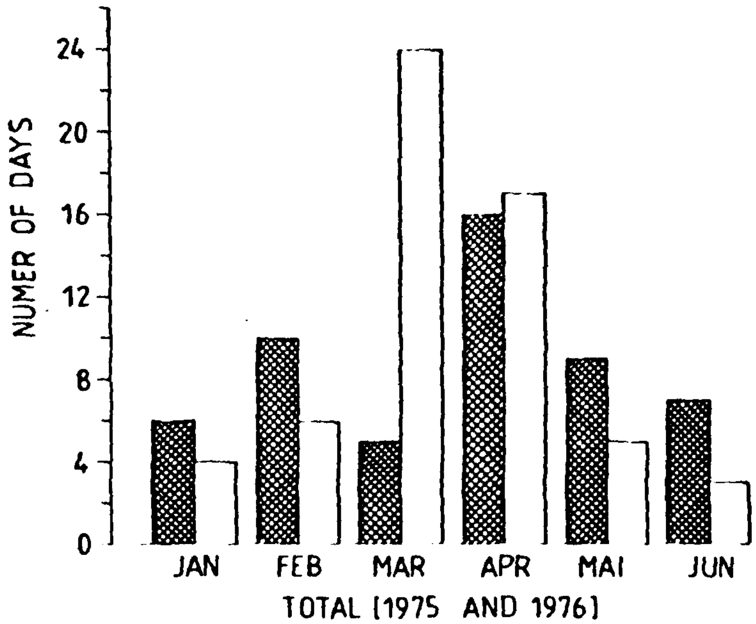

Fig. 29: January for 1975 and 1976.
The maximum abundance of days with large "n" in Spring is found one month later (April instead of March) on the more southern propagation path.

data gathered on the propagation path Coburg-Graz which resembled to that observed in Spain. This supports the presumption that the results presented here were not accidental but reflect some change (possibly in dynamics) which cause remains still unknown. The fact that the change of circulation at 90 - 100 km observed over central Europe does not coincide the observed increase of abundance of diurnal variations of absorption described by a large "n" seems to indicate that changes in heigths below 90 km may be of greater importance than changes which occur in greater heights. Unfortunately, no data are available which might support this supposition.

SUMMARY

The results described in this report show that radio wave absorption measurements can be used to monitor changes of the state of the D-region atmosphere. The height range from which information is gathered is however not well defined because the absorption measured by ground-based radio wave experiment is the integral of the product: electron density times electron collision frequency over a certain height range.

The height limits over which this integral extends remains unknown and is variable. The result of measurement is further affected by the properties of the ionospheric reflector which turns the probing wave back to ground. By proper choice of the experiment, the effects of the reflecting ionospheric layer upon absorption can be minimized but can never be eliminated completely. A detailed interpretation of absorption measurements in terms of atmospheric physics is therefore difficult if not impossible unless supporting experiments of other nature are carried out simultaneously.

But, as was shown in this report, a number of regular features can be seen in the diurnal and the seasonal variation of absorption. One of these features is the winter anomaly. The results show that winter anomaly was a regular phenomenon which occurred in every year without exception. The quasi-irregularity of its "begin" and "end" suggest that it might be caused by meteorological phenomena. The quasi-four-year period of phase - if considered real - might mean that a parametric oscillation of the D-region atmosphere may exist which is triggered by the quasi-biannal oscillation of the stratosphere. Parametric oscillations are generated when coupling between the two oscillating systems is not permanent but is present only for a certain time. An attempt to correlate changes of

atmospheric pressure measured on the ground with changes of absorption show that both parameters correlate during winter only. This may be taken as a hint that parametric oscillations of the D-region atmosphere are possible. Lack of relevant data from the stratosphere however did not allow a more detailed investigation.

It was shown that the diurnal variation of absorption yields also information about changes of state in the D-region when the measurements are carried out carefully and when the measurement circuit is properly designed. Nevertheless, the parameter "diurnal variation" is less well defined when figures have to be derived for a quantitative treatment.

It was shown here that the shape of diurnal variation undergoes certain variations with season. The variations are phenomenlogically similar to that found for the amplitude of absorption in the sense that a certain type of diurnal variation has a tendency to occur in groups of days in certain seasons. On grounds of comparisons one has some reason to assume that some of these groups of days are linked with the seasonal change of circulation in the D-region.

A relation between amount of absorption and shape of diurnal variation is not straightforward but depends upon season. This result explains why earlier attempts to find a relation between amount of absorption and shape of diurnal variation failed: The earlier attempts were based on averages over a whole year. Averages smooth out the change with season.

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